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(71) Applicant *(for all designated States except US)*: OPTICAL POWER SYSTEMS INC. [US/US]; 86 South Street, Hopkinton, MA 01748 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: DEMIDOV, Andrey, A. [RU/US]; 1110 Franklin Street, Duxbury, MA 02332 (US). STARODOUMOV, Andrei, N. [RU/US]; 293 Turnpike Road, Westborough, MA 01581 (US).

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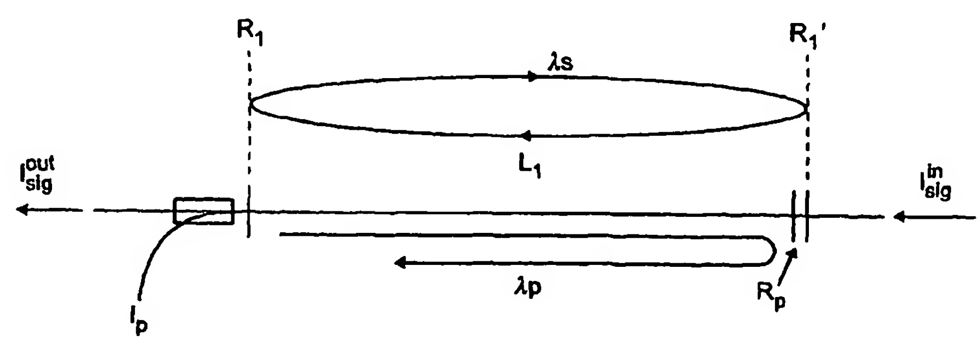
(54) Title: OPTICAL FIBER AMPLIFIER



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(57) Abstract: Optical fibers (e.g., fiber lasers and fiber amplifiers), and systems containing such optical fibers are disclosed.

Optical Fiber Amplifier

TECHNICAL FIELD

This invention relates to optical fibers (e.g., fiber lasers and fiber amplifiers), and systems containing such optical fibers. More particularly, the invention is directed toward fiber-based discrete optical amplifiers used in telecommunications, cable television and other fiber-optics applications.

BACKGROUND

In response to rising demand for information processing services, communications service providers have implemented optical communication systems, which have the capability to provide substantially larger information transmission capacities than traditional electrical communication systems. Information can be transported through optical systems in audio, video, data, or other signal format analogous to electrical systems. Likewise, optical systems can be used in telephone, cable television, LAN, WAN, and MAN systems, as well as other communication systems.

The development of the erbium doped fiber optical amplifier (EDFA) provided a cost effective means to optically amplify attenuated optical signal wavelengths in the 1550 nm range. EDFAs have been widely used in communication systems because their bandwidth coincides with the lowest loss window in optical fibers commonly employed in optical communication around 1550 nm. For wavelengths shorter than about 1525 nm, however, erbium atoms in typical glasses will absorb more than amplify. To broaden the gain spectra of EDFAs, various dopants have been added. For example, codoping of the silica core with aluminum or phosphorus can broaden the emission spectrum. Nevertheless, the absorption wavelength for various glasses is still around 1530 nm.

Raman fiber amplifiers offer an alternative to EDFAs.

Certain optical fibers can be used as fiber amplifiers or fiber lasers.

Fiber amplifiers are typically used to amplify an input signal. Often, the input signal and a pump signal are combined and passed through the fiber amplifier to amplify the signal at an input wavelength. The amplified signal at the input wavelength can then be isolated from the signal at undesired wavelengths.

Raman fiber lasers can be used, for example, as energy sources. In general, Raman fiber lasers include a pump source coupled to a fiber, such as an optical fiber, having a gain medium with a Raman active material. Energy emitted from the pump source at a certain wavelength λ_p, commonly referred to as the pump energy, is coupled into the fiber. As the pump energy interacts with the Raman active material in the gain medium of the fiber, one or more Raman Stokes transitions can occur within the fiber, resulting in the formation of energy within the fiber at wavelengths corresponding to the Raman Stokes shifts that occur (e.g., λ_{s1}, λ_{s2}, λ_{s3}, λ_{s4}, etc.).

Generally, the Raman active material in the gain medium of a Raman fiber laser may have a broad Raman gain spectrum. Usually, conversion efficiency varies for different frequencies within the Raman gain spectrum and many Raman active materials exhibit a peak in their gain spectrum, corresponding to the frequency with highest conversion efficiency. Additionally, the gain spectrum for different Raman active materials may be substantially different, partially overlapping, or of different conversion efficiency.

Typically, a Raman fiber laser is designed so that the energy formed at one or more Raman Stokes shifts is substantially confined within the fiber. This can enhance the formation of energy within the fiber at one or more higher order Raman Stokes shifts. Often, the fiber is also designed so that at least a portion of the energy at wavelengths corresponding to predetermined, higher order Raman Stokes shifts (e.g., λ_{sx}) where x is equal to or greater than one) is allowed to exit the fiber.

Raman fiber amplifiers can be adapted to amplify a broad range of wavelengths.

SUMMARY

In general, the invention relates to optical fibers (e.g., fiber lasers and fiber amplifiers), and systems containing such optical fibers.

In one aspect, the invention features a fiber amplifier for amplifying an optical signal having a signal wavelength. The fiber amplifier includes an optical fiber for transmitting the optical signal, a pump energy source and a plurality of waveguides. The optical fiber has a plurality of discrete portions. Each discrete portion includes first and second components disposed at first and second respective locations and configured to substantially prevent energy having an intermediate wavelength in the

discrete portion from entering other discrete portions of the optical fiber. The pump energy source is capable of emitting energy at a pump wavelength. Each waveguide is coupled to the pump energy source and to one of the plurality of discrete portions of the optical fiber. Each waveguide is configured to direct energy at the pump wavelength from the pump energy source to its corresponding discrete portion, thereby increasing an intensity of light at the discrete portion's intermediate wavelength in the corresponding discrete portion of the optical fiber. In embodiments, the fiber amplifier can be included in a system that also includes a signal source configured to direct the optical signal into the optical fiber, and a signal receiver configured to detect an output optical signal in the optical fiber. The output signal can be, for example, an optical signal that has been amplified by the fiber amplifier.

In another aspect, the invention features a fiber amplifier for amplifying an optical signal having a signal wavelength. The fiber amplifier includes an optical fiber having a plurality of discrete portions. Each discrete portion includes first and second components positioned at first and second respective locations in the discrete portion and configured to substantially prevent light having an intermediate wavelength in the portion from entering other portions of the optical fiber. The fiber amplifier also includes a coupler configured to couple pump energy from a pump energy source into the discrete portion so that the pump energy interacts with the optical fiber to increase the intensity of the intermediate wavelength in each portion.

In a further aspect, the invention features a fiber amplifier that includes an optical fiber having first and second sections coupled to each other. The first section is a double clad fiber laser, and the second section is an optical amplifier having a gain medium including P_2O_5. In embodiments, the fiber amplifier can be in a system that includes an input waveguide coupled to the second section of the fiber amplifier, and an output waveguide connected to the first coupler.

In certain embodiments, the fibers can be used as amplifiers rather than lasers.

Features, objects and advantages of the invention are in the description, drawings and claims.

DESCRIPTION OF DRAWINGS

Fig. 1 is a schematic representation of an embodiment of a fiber amplifier system;

Fig. 2 is a schematic representation of another embodiment of a fiber amplifier system;

Fig. 3 is a schematic representation of another embodiment of a fiber amplifier system;

Fig. 4 is a schematic representation of another embodiment of a fiber amplifier system;

Fig. 5 is a schematic representation of another embodiment of a fiber amplifier system; and

Fig. 6 is a schematic representation of a system including a fiber amplifier.

Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

Fig. 1 illustrates a single cascade discrete Raman amplifier 100 (ignoring $I_{sig}^{in}, I_{sig}^{out}$) in accordance with the present invention. Raman amplifier 100 is formed by mirrors R_1 and R_1' centered at the Stokes wave (λ_s) and is pumped by energy at pump wavelength λ_p. Without wishing to be bound by theory, it is believed that in general, the performance of Raman amplifier 100 can be described, at least in part, by the following system of nonlinear differential equations:

$$\begin{aligned}
\frac{dI_p^+(z)}{dz} &= -\frac{\lambda_s}{\lambda_p} g I_p^+(z)(I_s^+(z)+I_s^-(z)) - \alpha_p I_p^+(z) \\
\frac{dI_p^-(z)}{dz} &= \frac{\lambda_s}{\lambda_p} g I_p^-(z)(I_s^+(z)+I_s^-(z)) + \alpha_p I_p^-(z) \\
\frac{dI_s^+(z)}{dz} &= g(I_p^+(z)+I_p^-(z))I_s^+(z) - \alpha_s I_s^+(z) \\
\frac{dI_s^-(z)}{dz} &= -g(I_p^+(z)+I_p^-(z))I_s^-(z) + \alpha_s I_s^-(z)
\end{aligned} \qquad (1)$$

The indices $^+$ and $^-$ represent propagation in the fiber from left to right and from right to left, respectively. I_p and I_s represent the intensities of energy propagating the fiber at wavelengths λ_p and λ_s, respectively. g is the Raman gain coefficient. α_p and α_s are the loss coefficients of energy propagating in the fiber at wavelengths λ_p and λ_s, respectively.

These equations can be solved analytically and the following formula obtained:

$$(I_s^+ + I_s^-) = \frac{\lambda_p}{\lambda_s}\left(\frac{I_p}{\alpha_s L - \frac{1}{2}\ln(R_1 R_1')} - \frac{\alpha_p}{g}\right) \qquad (2)$$

Here, I_p is the power of the injected pump, and L is the length of the fiber. R_1 and R_1' represent the reflectivities of the reflectors (e.g., fiber Bragg gratings) in Fig. 1. This formula can give us the magnitude of the total intensity of the Stokes wave in the cavity. Equation (2) is the basic equation that gives the total Stokes power at λ_s and contains all cavity parameters as well as pump power. As an example for amplification of a signal at 1550 nm, the wavelengths are 1366 nm and 1452 nm.

We now consider that there is a signal wave introduced in the cavity (see Fig. 1) with power I_{sig}^{in} and the wavelengths shifted versus λ_s by the Raman Stokes shift. During its propagation through the cavity, the signal wave will be amplified through the mechanism of stimulated Raman scattering, which can be described by the following expression:

$$\frac{dI_{sig}(y)}{dy} = \left(\tilde{g}(I_s^+ + I_s^-) - \alpha_{sig}\right)I_{sig}(y), \qquad y = -z \qquad (3)$$

Here, $\tilde{g}$ is the Raman gain coefficient, and the system of coordinates is reversed (y = -z) for simplicity of calculation. The signal wave is considered weak enough not to deplete the Stokes wave. Equation (3) then has the following solution for the output signal:

$$I_{sig}^{out} = I_{sig}^{in} e^{\left(\tilde{g}(I_s^+ + I_s^-) - \alpha_{sig}\right)L} \qquad (4)$$

which gives us amplification in dB as follows:

$$K = 10\log\left(\frac{I_{sig}^{out}}{I_{sig}^{in}}\right) = 10\log(e)\left(\tilde{g}(I_s^+ + I_s^-) - \alpha_{sig}\right)L = 4.3\left(\tilde{g}(I_s^+ + I_s^-) - \alpha_{sig}\right)L \qquad (5)$$

We can then substitute Equation (2) in Equation (5) and obtain:

$$K = 4.3\left(\tilde{g}\frac{\lambda_p}{\lambda_s}\left(\frac{I_p}{\alpha_s L - \frac{1}{2}\ln(R_1 R_1')} - \frac{\alpha_p}{g}\right) - \alpha_{sig}\right)L \quad (6)$$

If we consider a completely closed cavity (i.e. $R_1 = R_1' = 1$), then

$$K = 4.3\left(\frac{\lambda_p}{\lambda_s}\left(\frac{\tilde{g}I_p}{\alpha_s} - \alpha_p\frac{\tilde{g}}{g}L\right) - \alpha_{sig}L\right) = 4.3\frac{\lambda_p}{\lambda_s}\left\{\frac{\tilde{g}I_p}{\alpha_s} - \left(\alpha_p\frac{\tilde{g}}{g} + \alpha_{sig}\frac{\lambda_s}{\lambda_p}\right)L\right\} \quad (7)$$

We can then roughly evaluate the pump power level required to achieve, for example, 10 dB gain in a 100 m cavity. The following values will be used:

$$\begin{aligned}
&\lambda_p = 1345\,nm\\
&\lambda_s = 1430\,nm\\
&g = 0.006\ 1/m/W\quad (highly\ GeO_2\ doped\ fiber)\\
&\tilde{g} = 0.005\ 1/m/W\\
&\alpha_p = 0.00032\ 1/m\\
&\alpha_s = 0.00026\ 1/m\\
&\alpha_{sig} = 0.00025\ 1/m\\
&L = 100\ m\\
&K = 10dB\\
&10 = 4.3\frac{1345}{1430}\left\{\frac{0.005\cdot I_p}{0.00026} - \left(0.00032\frac{0.005}{0.006} + 0.00025\frac{1430}{1345}\right)100\right\} = 4(19.2\cdot I_p - 0.053)
\end{aligned} \quad (8)$$

Finally,

$$\boxed{I_p = \frac{2.5 + 0.053}{19.2} = 0.133\,W} \quad (9)$$

Thus, 133 mW power at 1345 nm pump will provide amplification of 10 dB for a signal wave at about 1526 nm wavelength in a 100 m long cavity.

In a closed cavity with high finesse, the intensity of the Stokes wave builds up to a very high magnitude, which allows one to obtain very efficient amplification of a signal wave.

The in-cavity intensity of the Stokes wave for the same parameters (see, e.g., Equation (2)) is:

$$(I_s^+ + I_s^-) = \frac{\lambda_p}{\lambda_s}\left(\frac{I_p}{\alpha_s L - \frac{1}{2}\ln(R_1 R_1')} - \frac{\alpha_p}{g}\right) = \frac{1345}{1430}\left(\frac{0.133\,W}{0.00026\cdot 100} - \frac{0.00032}{0.006}\right) = 4.8\,W \qquad (10)$$

In a cavity having the parameters defined in (8) and pumped by I_p = 133 mW, the intensity of the Stokes wave is:

$$\boxed{(I_s^+ + I_s^-) = 4.8\,W} \qquad (11)$$

This result allows for the use of a single low power laser diode to obtain a high gain amplifier as shown in Fig. 1.

The current invention provides a highly efficient Raman amplifier suitable for a variety of applications. This invention further allows for a very simple, truly multiple wavelength, Raman amplifier because in this design one can isolate pieces of fiber for generation of individual Stokes waves λ_{si}, where i = 1, 2, 3, ..., using closed cavities, and generate a large number of these wavelengths using a relatively low pump power (1-2 W) at 13xx nm by sharing it between cavities. In this case, the intensities of individual Stokes waves can be easily and independently controlled by a power splitter. One example of such an amplifier 200 is shown in Fig. 2.

As shown in Fig. 2, instead of keeping all wavelengths (λ_{si}) together in the same lengths of fiber, they have been isolated from each other, thus reducing effects associated with their interaction. Further, the use of closed cavities allows the intensities of these waves to be kept constant along the lengths of the cavities. A further feature of the embodiment shown in Fig. 2 is that it works well with short cavities. For

example, Equation (7) shows that there is no L dependence scaled with I_p, while losses decrease with the shortening of L.

Fig. 3 shows another embodiment of an amplifier 300 in accordance with the present invention. The embodiment shown in Fig. 3 includes couplers 320, 322 and 324 (e.g., WDM couplers, circulators, etc.) that form ring cavities for generation of λs_i ($i = 1,\ldots, n$) Stokes waves in the 14yy nm wavelength domain. All reflectors R_p are highly reflective at the wavelength(s) of the master pump source (13xx nm). WDM couplers and/or circulators placed in the length of principle fiber that guides the amplified signal are selected so that they are completely "transparent" for an amplified WDM signal, but able to keep waves λ_i in the ring cavities. Amplification happens along the fiber lengths $L_1, L_2, \ldots, L_n$. The counter-propagation configuration of the presented amplifier reduces noise transfer from the pump to the amplified signal.

Fig. 4 shows a further embodiment of an amplifier 400 in accordance with the present invention. Amplifier 400 includes fiber laser 410 pumped by pump source 10. Pump source 10 can be one or more multimode laser diodes. Fiber laser 410 is preferably doped with Yb. The output of fiber laser 410 is preferably at approximately 1116 nm. The output of fiber laser 410 is used to pump a length of optical fiber 405. Optical fiber 405 is preferably about 1-2 km in length and doped with phosphorous (P_2O_5). Optical fiber 405 has two couplers 420 and 422, to provide separation of the pump and signal waves. Couplers 420 and 422 are preferably WDM couplers at 1116 and 1310 nm respectively. As shown in Fig. 4, signal 415 enters amplifier 400 from the right side, while pump wave 425 enters amplifier 400 from the left side, resulting in a counter-propagating amplification scheme. Other propagation schemes may be used (e.g. co-propagating amplification, etc.)

In the embodiment shown in Fig. 4, amplification occurs in optical fiber 405 according to the principle of stimulated Raman amplification. If optical fiber 405 is doped with P_2O_5 rather than GeO_2, a larger Stokes shift can be obtained (e.g., approximately 1330 cm^{-1} as compared with 420-440 cm^{-1}). This large Stokes shift allows for the use of the output from fiber laser 410 to directly pump optical fiber 405 to produce a simple, low cost optical amplifier at 1310 nm.

Fig. 5 shows a further embodiment of an amplifier 500 in accordance with the present invention. Amplifier 500 includes fiber laser 510 pumped by pump source 10. Pump source 10 can be one or more multimode laser diodes. Fiber laser 510 is

preferably doped with Yb. The output of fiber laser 510 is preferably downshifted to approximately 1286 nm. This output can be obtained through wavelength conversion (e.g., by using a multistage GeO_2/SiO_2 based Raman laser (shifter), single stage P_2O_5 based Raman laser (shifter), etc.) Shifters are described, for example, in commonly owned U.S. Provisional Patent Application Serial 60/302,603, filed on July 2, 2001, and entitled "Multi-Wavelength Optical Fiber," which is hereby incorporated by reference.

Referring again to Fig. 5, the output of shifter 530 is used to pump a length of optical fiber 505. Optical fiber 505 is preferably about 1-2 km in length and doped with phosphorous (P_2O_5). Optical fiber 505 has two couplers 520 and 522, to provide separation of the pump and signal waves. Couplers 520 and 522 are preferably WDM couplers at 1286 and 1550 nm respectively. As shown in Fig. 5, signal 515 enters amplifier 500 from the right side, while pump wave 525 enters amplifier 500 from the left side, resulting in a counter-propagating amplification scheme. Other propagation schemes may be used (e.g. co-propagating amplification, etc.)

In the embodiment shown in Fig. 5, amplification occurs in optical fiber 505 according to the well-known principle of stimulated Raman amplification. If optical fiber 505 is doped with P_2O_5 rather than GeO_2, a larger Stokes shift can be obtained (e.g., approximately 1330 cm^{-1} as compared with 420-440 cm^{-1}).

While the foregoing description has been made for a system in which the reflectance of a reflector is fixed. In some embodiments, the reflectance of a reflector can be variable. Various combinations of tunable reflectors are contemplated. Furthermore, these systems can include, for example, appropriate electronics to form a feedback loop so that the systems can monitor the intensity of energy output at one or more wavelengths and vary the reflectance of one or more reflectors (e.g., vary the reflectance of one or more reflectors in real time) to obtain one or more desired output intensities at one or more wavelengths. In certain embodiments, a reflector can be formed of a variable output coupler. Such couplers are described, for example, in commonly owned U.S. Provisional Patent Application Serial 60/300,298, filed on June 22, 2001, and entitled "Variable Spectrally Selective Output Coupler For Fiber Laser," which is hereby incorporated by reference.

While certain embodiments have been described, the invention is not limited to these embodiments. For example, the reflectors need not be in the form of fiber Bragg gratings. One or more of the reflectors can be a loop mirror, or one or more reflectors

can be in the form of a coated mirror (e.g., a coated mirror at one or both ends of a section of optical fiber), etc. As an additional example, the type of laser used for pumping can be varied. Examples of lasers that can be used include semiconductor diode lasers (e.g., high power semiconductor diode lasers), double clad doped fiber lasers, conventional free space coupled lasers, and the like. As another example, various types of optical fibers can be used, including, for example, double clad optical fibers and polarization maintaining optical fibers. Furthermore, the optical fibers can be formed of, for example, silica based materials (e.g., fused silica based) or fluoride-based materials. As yet another example, the relative and/or absolute lengths of one or more of the sections of the optical fiber can be varied based upon the intended use of the Raman fiber amplifier.

The foregoing fiber amplifiers can be used in a variety of situations. Fig. 6 is a schematic representation of a system 700 including a transmitter 710, an amplifier (e.g., one of the above-described amplifiers) 720 and a detector 730. Transmitter 710 and amplifier 720 are in optical communication via optical conduit (e.g., optical fiber) 740, and amplifier 720 and detector 730 are in optical communication via optical conduit (e.g., optical fiber) 750.

Other embodiments are in the claims.

WHAT IS CLAIMED IS:

1. A fiber amplifier for amplifying an optical signal having a signal wavelength, comprising:

a pump energy source capable of emitting energy at a pump wavelength;

an optical fiber for transmitting the optical signal, the optical fiber having a plurality of discrete portions, each discrete portion comprising first and second components disposed at first and second respective locations and configured to substantially prevent energy having an intermediate wavelength in the discrete portion from entering other discrete portions of the optical fiber; and

a plurality of waveguides, each waveguide coupled to the pump energy source and to one of the plurality of discrete portions of the optical fiber, each waveguide being configured to direct energy at the pump wavelength from the pump energy source to its corresponding discrete portion, thereby increasing an intensity of light at the discrete portion's intermediate wavelength in the corresponding discrete portion of the optical fiber.

2. The fiber amplifier of claim 1, wherein the intermediate wavelength of each of the plurality of discrete portions is equal to the pump energy wavelength Stokes shifted one or more times.

3. The fiber amplifier of claim 1, wherein for at least one of the discrete portions the first and second components comprise reflectors configured to reflect substantially all energy impinging thereon at the discrete portion's intermediate wavelength and to transmit substantially all energy at the signal wavelength.

4. The fiber amplifier of claim 3, wherein the reflectors comprise fiber Bragg gratings.

5. The fiber amplifier of claim 3, wherein one of the plurality of waveguides is configured to couple energy at the pump wavelength into the at least one discrete portion.

6. The fiber amplifier of claim 5, further comprising a pump beam coupler attached to the at least one discrete portion and to the one of the plurality of

waveguides, the pump beam coupler being configured to couple energy at the pump wavelength from the one of the plurality of waveguides into the at least one discrete portion.

7. The fiber amplifier of claim 5, wherein the at least one discrete portion includes a pump energy reflector configured to reflect substantially all energy impinging thereon at the pump wavelength.

8. The fiber amplifier of claim 1, further comprising a cavity fiber having first and second ends respectively attached to the first and second components of one of the discrete portions.

9. The fiber amplifier of claim 1, wherein for at least one of the discrete portions the first component comprises a first coupler configured to couple energy having the discrete portion's intermediate wavelength into the discrete portion of the optical fiber.

10. The fiber amplifier of claim 9, wherein for the at least one of the discrete portions the second component comprises a second coupler configured to couple light having the discrete portion's intermediate wavelength out of the discrete portion of the optical fiber.

11. The fiber amplifier of claim 9, wherein the first and second couplers each comprise a wavelength division multiplexer.

12. The fiber amplifier of claim 9, wherein the first and second couplers each comprise a circulator.

13. The fiber amplifier of claim 1, wherein at least one of the discrete portions further comprises a cavity fiber having first and second ends respectively attached to the first and second components of the at least one discrete portion.

14. The fiber amplifier of claim 13, wherein the at least one discrete portion and the cavity fiber define a ring cavity for energy having the discrete portion's intermediate wavelength.

15. The fiber amplifier of claim 14, wherein the first coupler is configured to couple energy having the discrete portion's intermediate wavelength out of the cavity fiber into the at least one discrete portion and the second coupler is configured to couple energy having the discrete portion's wavelength out of the at least one discrete portion and into the cavity fiber.

16. The fiber amplifier of claim 13, further comprising first and second reflectors disposed in the cavity fiber and configured to reflect substantially all energy impinging thereon at the pump wavelength.

17. The fiber amplifier of claim 16, further comprising a waveguide coupler attached to the cavity fiber and to one of the plurality of waveguides, the waveguide coupler being configured to couple energy having the pump wavelength from the waveguide into the cavity fiber.

18. The fiber amplifier of claim 17, wherein the waveguide coupler is located between the first reflector and the second reflector disposed in the cavity waveguide.

19. The fiber amplifier of claim 13, wherein the cavity fiber has a gain medium comprising an active material.

20. The fiber amplifier of claim 19, wherein the active material is GeO_2.

21. The fiber amplifier of claim 19, wherein the active material is P_2O_5.

22. The fiber amplifier of claim 1, wherein the optical fiber has a gain medium comprising an active material.

23. The fiber amplifier of claim 22, wherein the active material is GeO_2.

24. The fiber amplifier of claim 22, wherein the active material is P_2O_5.

25. The fiber amplifier of claim 1, wherein the pump energy source comprises a splitter configured to couple pump energy into the plurality of waveguides.

26. The fiber amplifier of claim 25, wherein splitter is configured to variably couple pump energy into the plurality of waveguides.

27. The fiber amplifier of claim 1, wherein the pump energy source comprises a laser.

28. The fiber amplifier of claim 27, wherein the pump energy source comprises a plurality of lasers.

29. The fiber amplifier of claim 28, wherein each of the plurality of lasers corresponds to one of the discrete portions of the optical fiber.

30. The fiber amplifier of claim 1, wherein the pump energy source comprises laser diode.

31. The fiber amplifier of claim 1, wherein the pump energy source has a power of less than 5W.

32. The fiber amplifier of claim 1, wherein the pump energy source has a power of less than 2W.

33. The fiber amplifier of claim 1, wherein the pump energy source has a power of less than 1W.

34. The fiber amplifier of claim 1, wherein the pump energy wavelength is between 1300 nm and 1400 nm.

35. The fiber amplifier of claim 1, wherein at least one of the discrete portion's intermediate wavelength is between 1400 nm and 1500 nm.

36. The fiber amplifier of claim 1, wherein the signal wavelength is between 1500 nm and 1600 nm.

37. A system, comprising:

the fiber amplifier of claims 1-36;

a signal source configured to direct the optical signal into the optical fiber;

a signal receiver configured to detect an output optical signal in the optical fiber, the output signal being an optical signal that has been amplified by the fiber amplifier.

38. A fiber amplifier for amplifying an optical signal having a signal wavelength, comprising:

an optical fiber having a plurality of discrete portions, each discrete portion comprising:

first and second components positioned at first and second respective locations in the discrete portion and configured to substantially prevent light having an intermediate wavelength in the portion from entering other portions of the optical fiber; and

a coupler configured to couple pump energy from a pump energy source into the discrete portion so that the pump energy interacts with the optical fiber to increase the intensity of the intermediate wavelength in each portion.

39. The fiber amplifier of claim 38, wherein for at least one of the discrete portions the first and second components comprise reflectors configured to reflect substantially all energy impinging thereon at the discrete portion's intermediate wavelength and to transmit substantially all energy at the signal wavelength.

40. The fiber amplifier of claim 39, wherein the reflectors comprise fiber Bragg gratings.

41. The fiber amplifier of claim 38, wherein at least one discrete portion includes a pump energy reflector configured to reflect substantially all energy impinging thereon at the pump wavelength.

42. The fiber amplifier of claim 38, further comprising a cavity fiber having first and second ends respectively attached to the first and second components of one of the discrete portions.

43. The fiber amplifier of claim 42, wherein the at least one discrete portion and the cavity fiber define a ring cavity for energy having the discrete portion's intermediate wavelength.

44. The fiber amplifier of claim 43, wherein the first coupler is configured to couple energy having the discrete portion's intermediate wavelength out of the cavity fiber into the at least one discrete portion and the second coupler is configured to couple energy having the discrete portion's wavelength out of the at least one discrete portion and into the cavity fiber.

45. The fiber amplifier of claim 42, further comprising first and second reflectors disposed in the cavity fiber and configured to reflect substantially all energy impinging thereon at the pump wavelength.

46. The fiber amplifier of claim 38, wherein for at least one of the discrete portions the first component comprises a first coupler configured to couple energy having the discrete portion's intermediate wavelength into the discrete portion.

47. The fiber amplifier of claim 46, wherein for the at least one of the discrete portions the second component comprises a second coupler configured to couple light having the discrete portion's intermediate wavelength out of the discrete portion of the optical fiber.

48. The fiber amplifier of claim 47, wherein the first and second couplers each comprise a wavelength division multiplexer.

49. The fiber amplifier of claim 47, wherein the first and second couplers each comprise a circulator.

50. The fiber amplifier of claim 38, further comprising a plurality of waveguides each configured to couple energy at the pump wavelength from the energy source into a coupler.

51. The fiber amplifier of claim 50, wherein each of the plurality of waveguides is configured to couple energy at the pump wavelength from the pump energy source into a coupler of a corresponding one of the plurality of discrete portions.

52. A fiber amplifier, comprising:

an optical fiber having first and second sections coupled to each other,

wherein the first section is a double clad fiber laser, and the second section is an optical amplifier having a gain medium including P_2O_5.

53. The fiber amplifier of claim 52, wherein during operation the fiber amplifier amplifies energy propagating in the second section of the optical fiber having a signal wavelength between 1,300 nm and 1,400 nm.

54. The fiber amplifier of claim 52, further comprising an pump energy source configured to pump the first section of the optical fiber.

55. The fiber amplifier of claim 54, wherein the pump energy source comprises a pump diode.

56. The fiber amplifier of claim 52, further comprising a first coupler disposed in the second section and configured to couple energy having a signal wavelength out of the optical fiber.

57. The fiber amplifier of claim 52, further comprising a second coupler disposed in the second section and configured to couple energy at the first wavelength out of the optical fiber.

58. The fiber amplifier of claim 56, wherein the first wavelength is related to the signal wavelength by a Stokes shift of more than 1,000 cm^{-1}.

59. A system comprising:

an input waveguide coupled to the second section of the fiber amplifier of claims 52-58; and

an output waveguide connected to the first coupler.

60. The system of claim 59, wherein the input waveguide is an optical fiber.

61. The system of claim 60, wherein the input optical fiber is a single mode optical fiber.

62. The system of claim 59, wherein the output waveguide is an output optical fiber.

63. The system of claim 62, wherein the output optical fiber is a single mode optical fiber.

64. The system of claim 59, further comprising a signal source configured to direct energy having a signal wavelength into the input waveguide.

65. The system of claim 59, further comprising a signal receiver configured to receive energy having a signal wavelength in the optical fiber.

66. The fiber amplifier of claim 52, further comprising a fiber laser capable of emitting energy having a pump wavelength coupled to the first section of the optical fiber.

67. The fiber amplifier of claim 66, wherein the pump wavelength is greater than 1,040 nm.

68. The fiber amplifier of claim 66, wherein the pump wavelength is greater than 1,100 nm.

69. The fiber amplifier of claim 66, wherein the first wavelength is between 1,200 nm and 1,300 nm.

70. The fiber amplifier of claim 66, wherein the fiber laser is a Raman fiber laser.

71. The fiber amplifier of claim 70, wherein the Raman fiber laser has a gain medium comprising GeO_2.

72. The fiber amplifier of claim 70, wherein the Raman fiber laser has a gain medium comprising P_2O_5.

73. The fiber amplifier of claim 66, wherein during operation the fiber amplifier amplifies energy propagating in the second section of the optical fiber having a signal wavelength between 1,500 nm and 1,600 nm.

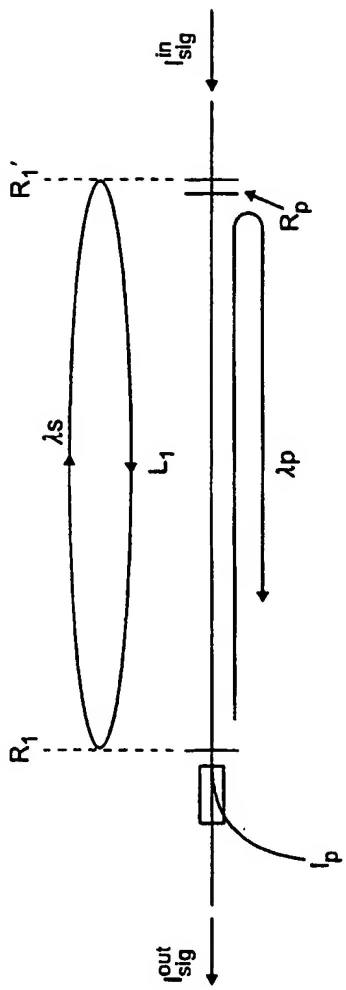
I_{sig}^{in}
R_1'
R_p
λs
L_1
λp
R_1
I_p
I_{sig}^{out}

FIG. 1

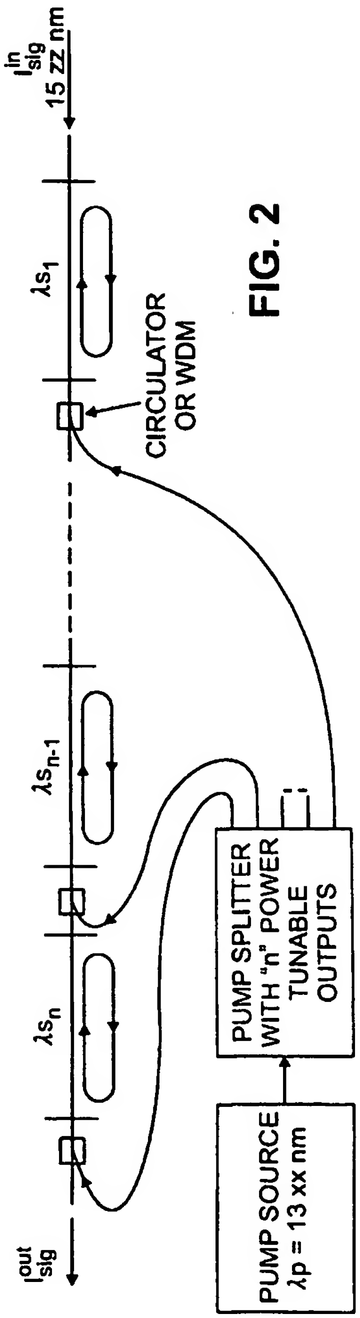
I_{sig}^{in}
15 zz nm
λs_1
CIRCULATOR
OR WDM
λs_{n-1}
λs_n
PUMP SPLITTER
WITH "n" POWER
TUNABLE
OUTPUTS
PUMP SOURCE
λp = 13 xx nm
I_{sig}^{out}

FIG. 2

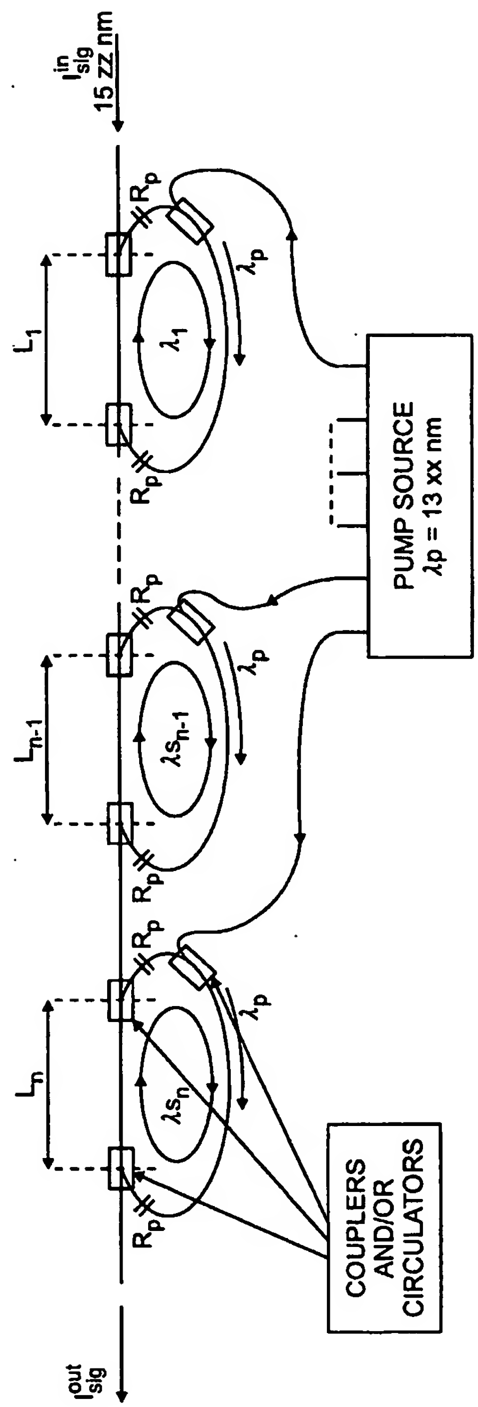
I_{sig}^{in}
15 zz nm
L_1
λ_1
λ_p
R_p
PUMP SOURCE
λp = 13 xx nm
L_{n-1}
λs_{n-1}
L_n
λs_n
COUPLERS
AND/OR
CIRCULATORS
I_{sig}^{out}

FIG. 3

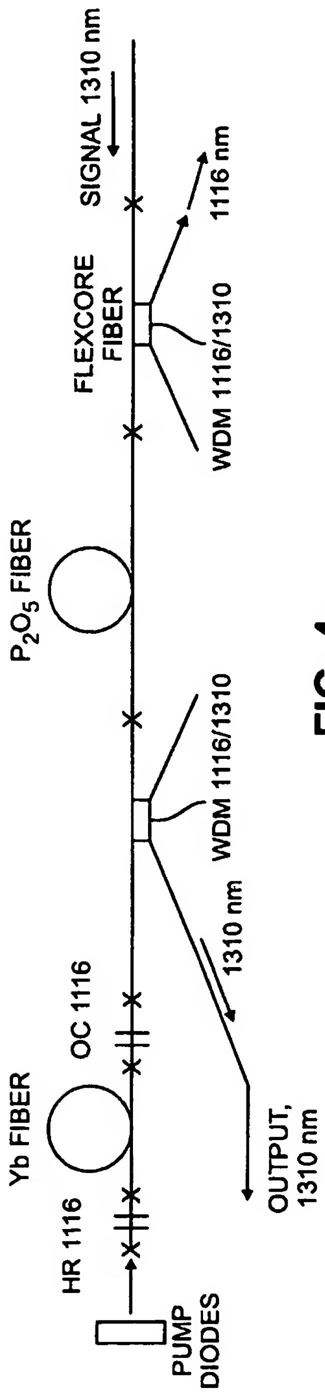
PUMP DIODES
HR 1116
Yb FIBER
OC 1116
OUTPUT, 1310 nm
1310 nm
WDM 1116/1310
P_2O_5 FIBER
WDM 1116/1310
FLEXCORE FIBER
1116 nm
SIGNAL 1310 nm

FIG. 4

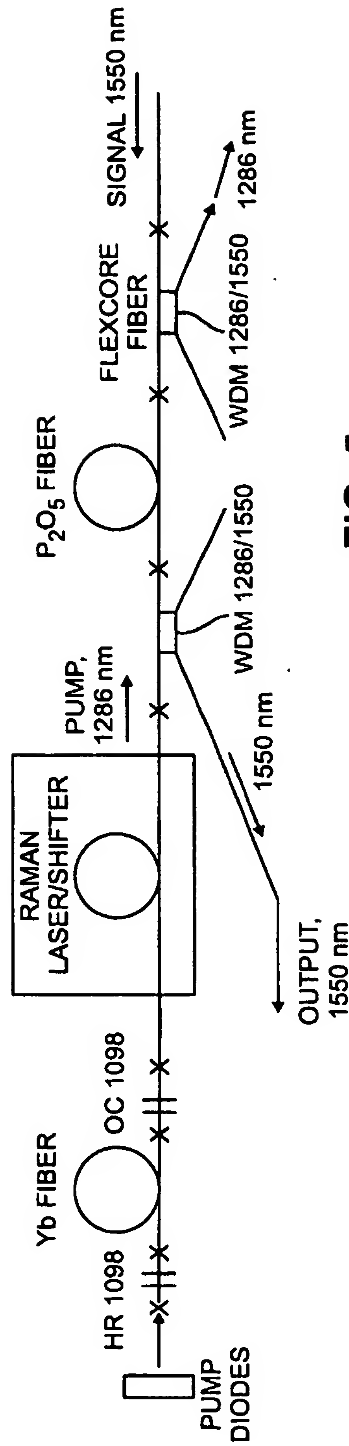
PUMP DIODES
HR 1098
Yb FIBER
OC 1098
RAMAN LASER/SHIFTER
OUTPUT, 1550 nm
1550 nm
PUMP, 1286 nm
WDM 1286/1550
P_2O_5 FIBER
WDM 1286/1550
FLEXCORE FIBER
1286 nm
SIGNAL 1550 nm

FIG. 5

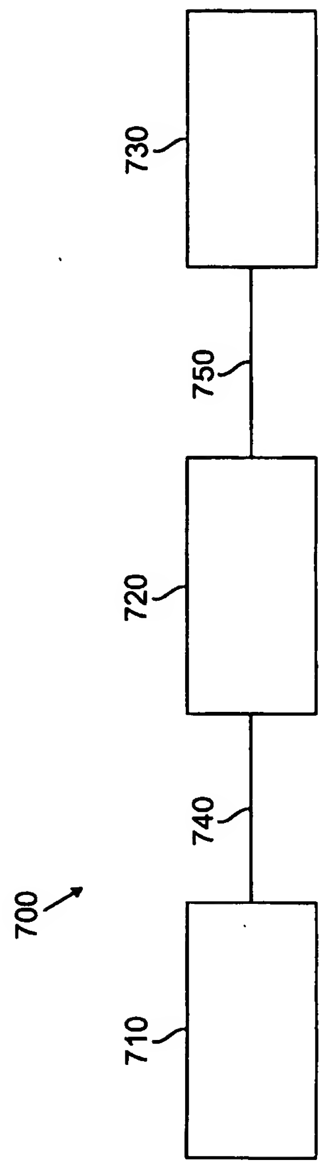

FIG. 6